Examining the Geological Potential for Helium Production in the United States

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By

Thomas Phetteplace

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Approved by

Thomas H. Darrah, Advisor
School of Earth Sciences

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Abstract

Global helium demand has more than doubled throughout the last twenty years in response to the development of new manufacturing and scientific research techniques. In fact, data collected by the National Science Academies have shown that global demand for helium is likely to outstrip global supply by 2020. Despite these rapid increases in helium demand and the looming shortfall in helium supplies, recent United States federal legislation has mandated the deregulation of the U.S. federal helium reserve managed by the U.S. Bureau of Land Management. Because the United States has been a global leader in the recovery and storage of helium since the early 1900s, and continues to be the leading global producer and reserve holder of helium today, this decision has created considerable uncertainty in global helium markets. As a result, other countries such as Qatar, Algeria, and Russia have begun to develop their own helium resources. These changes in global helium markets highlight the need to characterize domestic unconventional helium reserves globally. This research examines the potential for helium production in the United States.

Introduction

Helium (He) is one of the most useful and often undervalued resources on Earth. Despite common public perception that helium is largely used to fill blimps and balloons, it is now widely used for various industrial and scientific activities, such as magnetic resonance imaging (MRI) machines, detecting gas leaks, arc welding, and as a coolant for various types of scientific equipment (Bureau of Land Managment 2014). Only with the advent of recent news reports of a helium shortage have many people begun to realize the scope of helium's importance to research, medicine, and manufacturing activities in the United States (U.S.).

The U.S. federal government has been involved with the refining and storage of helium since the first half of the twentieth century, and continues to enact laws to ensure its future availability (Bureau of Land Managment 2014). The United States has a significant percentage (roughly 40%) of the global helium reserves (Hamak 2014), with most of the current production occurring as a byproduct of natural gas collection. In fact, most helium production occurs within the state of Texas in an area known as the Hugoton Panhandle (Hamak 2014). In addition to U.S. domestic resources, large He reserves can be found in Qatar, Algeria, Russia, Canada and China (Figure 2), which make up together roughly 56% of the remaining global supply (Hamak 2014).

Novel technological developments have been increasing the demand for helium beyond current production. According to the National Academies 2010 helium report, the U.S. and other nations have begun taking steps to increase the production and refining of helium to meet global demand (National Research Council 2010). Helium production is hampered by its relatively low concentrations within many existing reservoirs, requiring a concentration of 0. 3% by volume before it becomes economically viable (National Research Council 2010). The United States has several advantages in the production of helium over other nations due to its existing infrastructure, which started in 1925 with the creation of the Federal Helium Program (Bureau of Land Managment 2014) and continuing in 1960 with the establishment of the Cliffside Storage Facility outside of Amarillo, Texas (National Research Council 2010).

Background Information

Helium is one of the most abundant elements in our universe, however it is exceedingly rare on Earth (National Research Council 2010). Helium has two stable isotopes (both with two protons): the more common ^{4}He contains two neutrons, while ^{3}He contains only one neutron (Hampel 1968). Helium-4 is a remnant from the formation of the planet (referred to as primordial helium) and is created as a byproduct of the alpha decay of radioactive elements such as uranium (U) and thorium (Th) ($^{238}_{92}U \Rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$). As a result of radioactive decay, it is constantly being produced within the Earth's interior (Chang 2010) specifically within U- and Th-rich sedimentary sequences in the earth's crust (e.g., black shales) (Selley 1985). By comparison, ^{3}He is either a remnant from the formation of the planet (referred to as primordial helium) or results from the beta decay of tritium ($^{3}_{1}H \Rightarrow {}^{3}_{2}He^{1+} + e^{-} + v_{e}$). Tritium is an isotope of hydrogen created either naturally by cosmogenic radiation or during the production of nuclear warheads (Shea and Morgan 2010). Due to its low relative density compared with other gases in the Earth's atmosphere, helium is quickly lost to space by hydrodynamic escape mechanisms (National Research Council 2010).

Helium is an inert noble gas that rarely undergoes reactions with other elements (Chang 2010). He remains in the gas-phase under most conditions unless cooled to a very low temperature (4.2 Kelvin at 1 atmosphere) or exposed to very high pressures as a pure helium phase (more than 25 atmospheres) (National Research Council 2010). These properties of helium make it valuable in areas such as welding, semiconductor manufacturing, and nearly irreplaceable in scientific research as a refrigerant (National Research Council 2010).

Currently helium is most commonly used in the United States as a coolant (Figure 1). It is used in medical equipment, such as MRI machines, which require the use of helium as a coolant to allow for the operation of a strong superconducting magnet (National Research Council 2010). Helium is also used in scientific research where temperatures approaching 0 K are required, such as superconductors for particle accelerators and particle detectors (National Research Council 2010). Due to its limited reactivity, helium is used in manufacturing, particularly in the manufacturing of optical fibers and semiconductors (National Research Council 2010). The isotope ^3He is used as a neutron detector at security checkpoints to detect the illegal transport of nuclear material, and in geological well logging equipment (Shea and Morgan 2010).

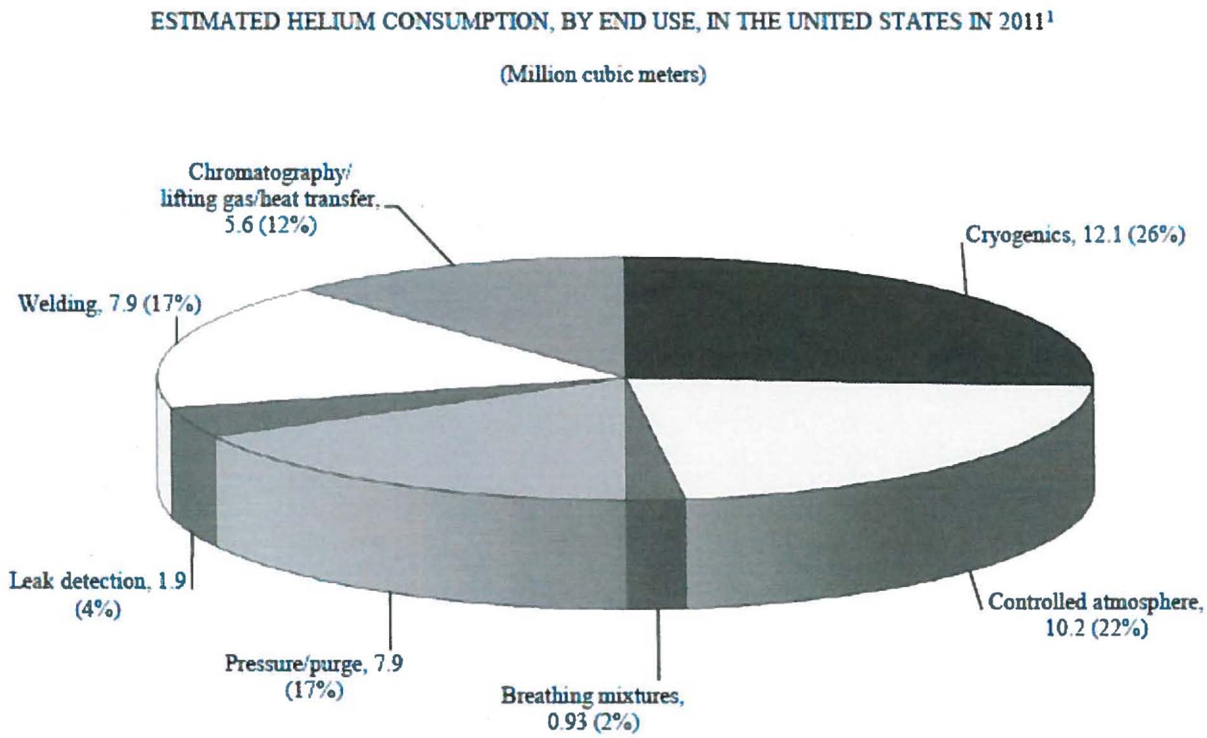

Figure 1. Source: U.S. Geological Survey 2011 Minerals Yearbook (Peterson and Madrid 2011) *http://minerals.usgs.gov/minerals/pubs/commodity/helium/myb1-2011-heliu.pdf. This figure shows the U.S. helium consumption by its most common uses. Uses as a coolant and as an inert gas for manufacturing make up almost 50% of the total consumption as of 2011.*

The United States' commitment to a national supply of helium began when Congress passed the Helium Act of 1925, which established the Federal Helium Program and that it be managed by the Bureau of Mines, and later the Bureau of Land Management (National Research

Council 2010). Since then, the United States government has invested in a system of helium pipelines along the He producing natural gas fields, such as the Hugoton, Panhandle, Greenwood and Keys fields found in Kansas, Oklahoma and Texas, and the development of the National Helium Reserve at the Cliffside Storage Facility outside of Amarillo, Texas (Gage and Driskill 2004). In 1996, the Helium Privatization Act was passed to begin the process of privatizing the helium supply industry and to recoup some of the expense of creating and maintaining the program (Committee Reports 113th Congress (2013-2014) House Report 113-042). In 2013, the Responsible Helium Administration and Stewardship Act was passed in order to delay the deadline for privatization from 2015 up to 2021 and to change the ways in which the helium is sold (H.R.527 - Helium Stewardship Act of 2013).

Commercial helium production in the United States occurs in Wyoming, Utah, Colorado, New Mexico, Kansas, Oklahoma, and Texas (Figure 2). The Hugoton-Panhandle complex found in Kansas, Oklahoma, and Texas is one of the largest helium gas reservoirs in the United States, and is composed of two separate stratigraphic traps. The trap found in the Hugoton is created by an updip facies change from marine carbonates to nonmarine clastics with low permeability, and the trap in the Panhandle section is a structural trap above the Amarillo-Wichita uplift (Ballentine and Lollar 2002). The main production zone is found in Permian-aged carbonate formations (Chase, Panoma, Wabaunsee and Shawnee) that are the result of migration of gases from the Anadarko Basin. Ballentine and Lollar concluded that the helium found in the Hugoton-Panhandle was due to the decay of Th and U followed by fluid migration within the Anadarko Basin, a shallow source composed of sedimentary rock (roughly 60%), and a lower source of crystalline basement rock. It is found in traps alongside other low density gases such as methane

(CH_4) and nitrogen (N_2) (Ballentine and Lollar 2002) because these gases require low porosity and low permeability seals to prevent their escape in to the atmosphere (Selley 1985).

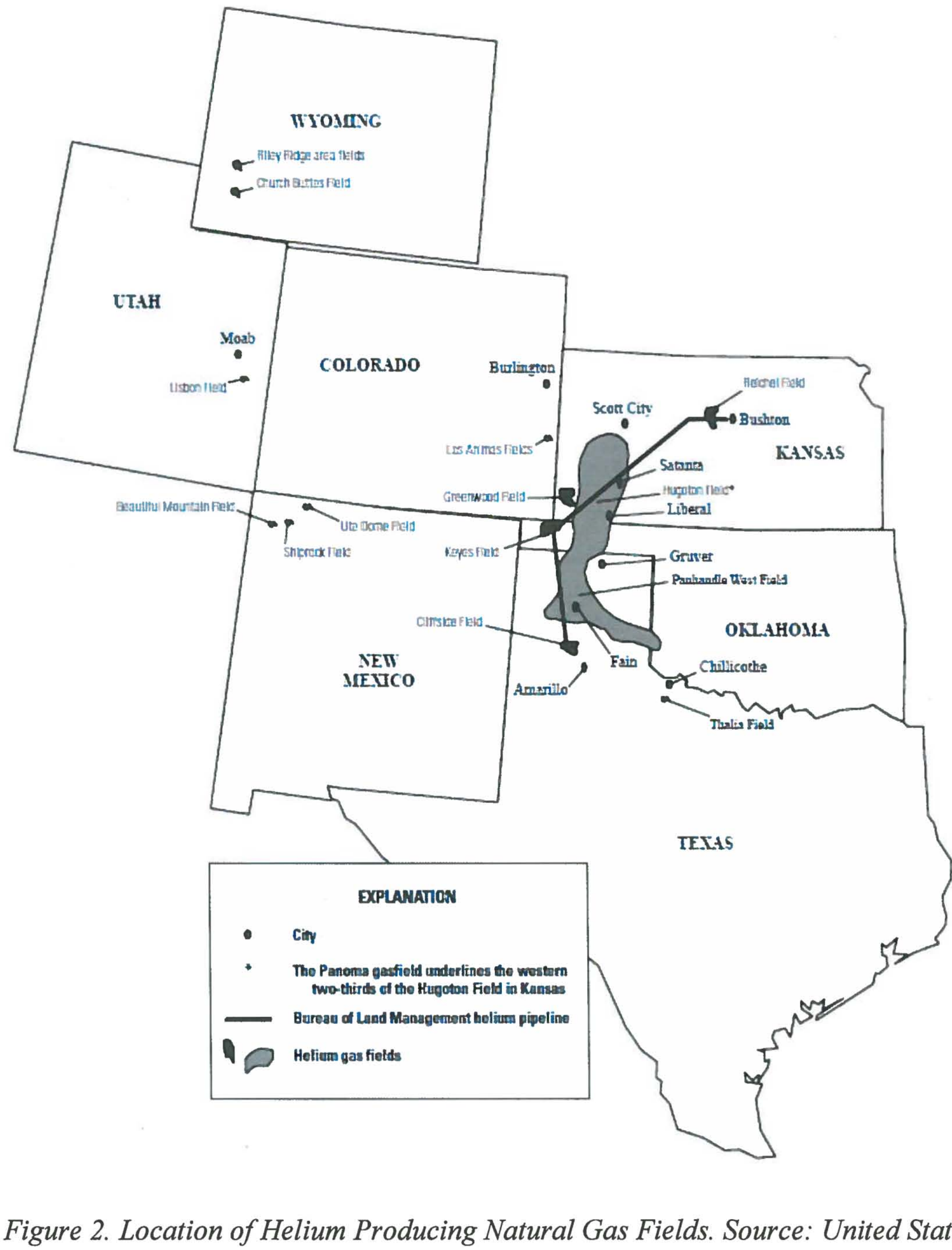

Figure 2. Location of Helium Producing Natural Gas Fields. Source: United States' Geological Survey 2011 Minerals Yearbook (Peterson and Madrid 2011) *at* [http://minerals.usgs.gov/minerals/pubs/commodity/helium/myb1-2011-heliu.pdf.](http://minerals.usgs.gov/minerals/pubs/commodity/helium/myb1-2011-heliu.pdf) *This figure shows the distribution of the major helium producing natural gas fields in the United States as well as the location of the Cliffside facility northwest of Amarillo, Texas.*

Helium recovered from natural gas reservoirs must be refined before it can be stored and sold to academia and industry (National Research Council 2010). With helium making up such a small percentage of natural gas, multiple steps are required to remove different components of the gas until the remaining percentage of helium is high enough (between 50 to 70%) to be further refined or stored for later refinement (National Research Council 2010). This crude helium can be refined to a 99.99% purity through either the use of active charcoal absorbers at low temperatures, or by pressure-swing adsorption (Das et al. 2008). The final step is liquefaction for transport. According to the Congressional Research Service, the ability to separate ^{3}He from ^{4}He further has been shown to be successful in a laboratory setting and could be expanded to an industrial scale. The ^{3}He can then be used in specific cases, such as neutron detectors, MRI's and cryogenics where ^{4}He cannot be used (Shea and Morgan 2010).

Compilation of Data

The USGS estimates the helium resources in the United States to be approximately 20.6 billion cubic meters (744 billion cubic feet), which is 40% of the estimated global resources (Hamak 2014). This amount includes 4.25 billion cubic meters of measured reserves, 5.33 billion cubic meters of probable reserves, 5.93 billion cubic meters of possible, and 5.11 billion cubic meters of speculative reserves. Qatar (10.1 billion cubic meters), Algeria (8.2 billion cubic meters), and Russia (6.8 billion cubic meters) represent the next largest helium resources on the planet (Hamak 2014). This puts the United States in an enviable global position because it has the largest helium resources and the most developed recovery and production infrastructure. With growing natural gas production, the U.S. now has the opportunity to begin He production in unconventional reservoirs such as shale gas. However, with the increased global demand for helium, other nations have begun the process of bringing new helium production facilities online. The National Academies reported on the development of additional refining facilities in Qatar and Algeria (National Research Council 2010). As of December 2013, the world's largest helium refining facility, the Helium 2, was inaugurated in Qatar (Ras Gas Company Limited 2013).

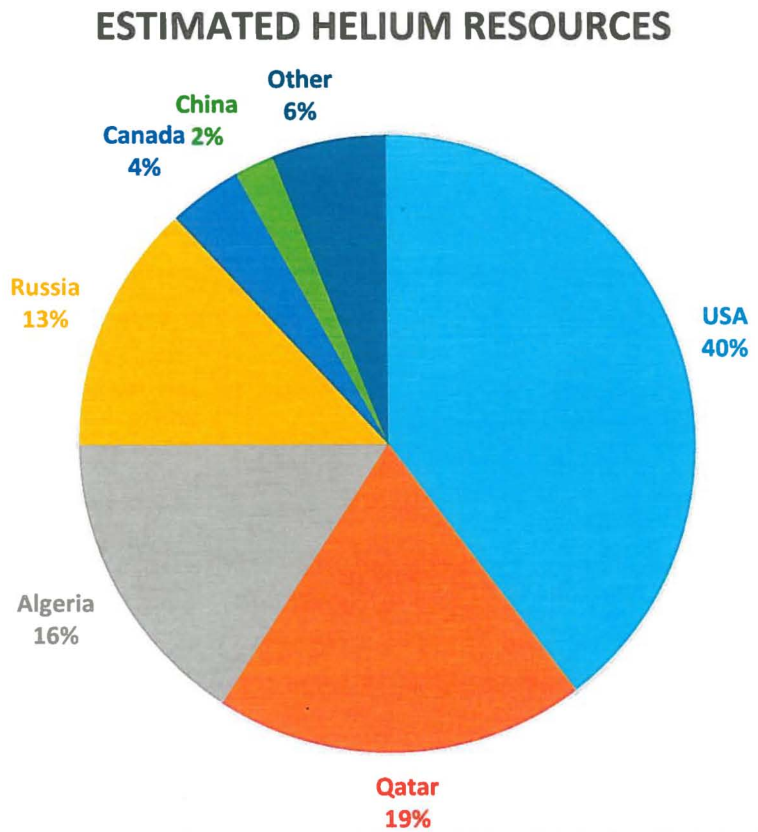

Figure 3. Percentage of Estimated Helium Resources by Country. Source: United States' Geological Survey, Mineral Commodity Summaries, February 2014 at http://minerals.usgs.gov/minerals/pubs/commodity/helium/mcs-2014-heliu.pdf. This chart shows the total global estimated helium resources by country. The US has the largest percentage due to its abundance of natural gas, however Qatar, Algeria and Russia also control a sizable portion of the total and will likely increase their production in the future.

According to the USGS, the value of the total privately extracted "Grade A Helium" in the United States was 930 million dollars, with a price of approximately $7.21 per cubic meter (Hamak 2014). Helium production has remained relatively flat over the last five years. Table 1 represents the five year breakdown provided by the USGS report. Figure 4 shows the production of natural gas from 1900 until present. The production of natural gas in the U.S. has been consistently increasing since 1900 and in particular over the last ten years (U.S. Energy Information Administration 2014). The increase in overall natural gas production has not seen an increase in helium production as seen in Table 1. Much of the discrepancy is due to refining capacity lagging well behind production (National Research Council 2010).

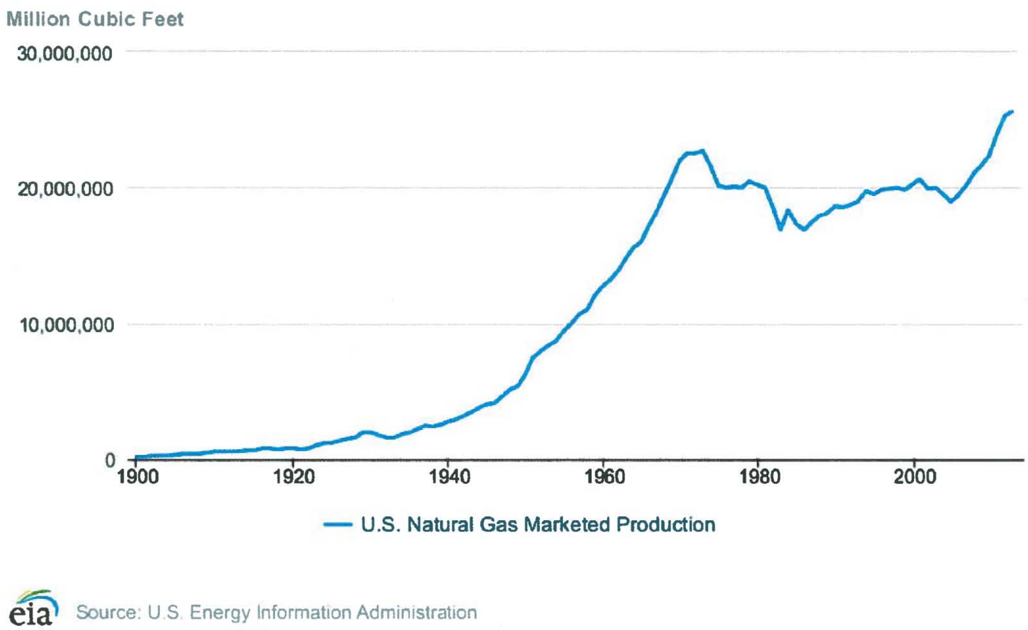

Figure 4 Source: The U.S. Energy Information Administration (U.S. Energy Information Administration 2014). This figure shows the production of natural gas in the U.S. from 1900 until the present. It is important to note the recent increase in production which is due in part to unconventional reservoirs such as shale gas reservoirs.

Table 1. Helium Production Statistics for the United States
Source: United States Geological Survey Helium Statistics and Information *http://minerals.usgs.gov/minerals/pubs/commodity/helium/mcs-2014-heliu.pdf. This table shows and increase in helium sales with an increase in exports while the domestic production remains flat.*

Salient Statistics—United States:	2009	2010	2011	2012	2013[e]
Helium extracted from natural gas[2]	78	75	71	73	77
Withdrawn from storage[3]	40	53	59	60	52
Grade-A helium sales	118	128	130	133	129
Imports for consumption	—	—	—	—	—
Exports[4]	71	77	82	85	82
Consumption, apparent[4, 5]	47	51	48	48	47

Currently, the production of helium does not meet the global demand for helium (Hamak 2014). The "Withdraw from Storage" section refers to the government mandated drawdown of its long term helium storage at Cliffside Storage Facility (Hamak 2014). The long term trends in the helium industry show the leveling off of domestic demand with a concurrent increase in foreign demand (National Research Council 2010). The Nation Academy of Science produced a report in 2010 (Figure 5), which looked at current and future demand for helium. This report demonstrated that the foreign demand has been increasing steadily over the last 30 years (National Research Council 2010).

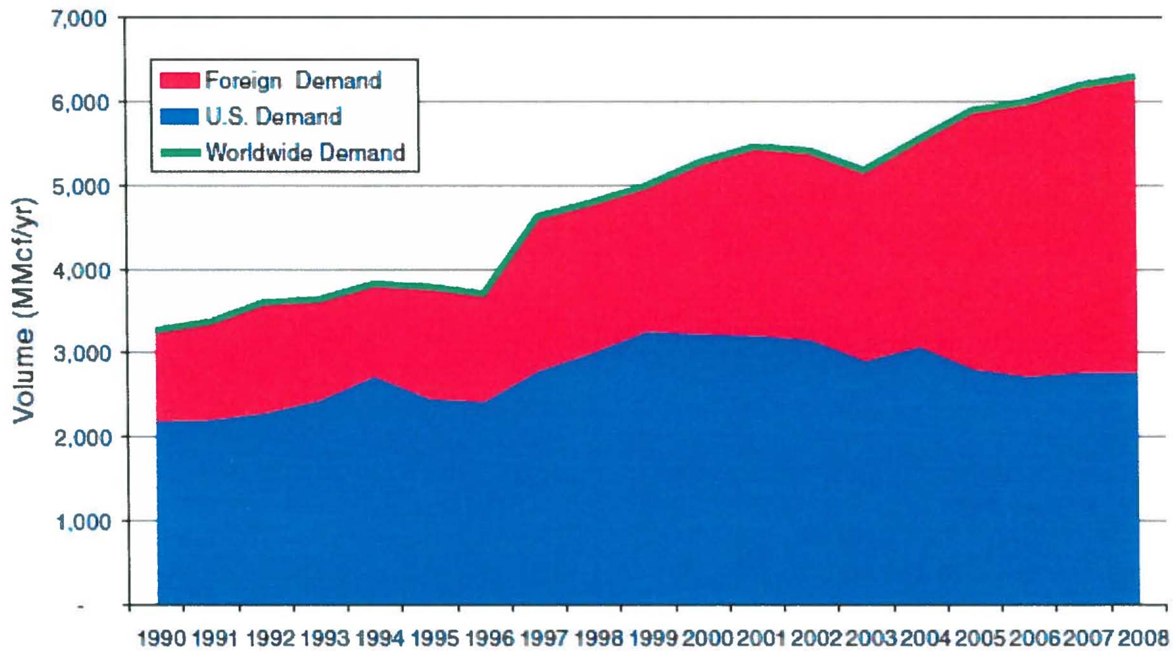

Figure 5. Global demand for helium. Source: Selling the Nation's Helium Reserve, The National Academies 2010. The graph shows the worldwide demand for helium from 1990 to 2008. A clear upward trend is seen in foreign demand for helium and a flat demand in the United States. These increases are mostly due to the increase in manufacturing facilities outside the U.S. (National Research Council 2010)

Current global production is dominated by the United States. In 2013, the U.S. supplied 129 million cubic meters of helium, ~ 75% of the total global production (Hamak 2014). This is far more than the rest of the world combined. However, these numbers are slightly inflated due to the fact that 52 million cubic meters were sourced from previously recovered helium from storage with the strategic helium reserve (Hamak 2014). The remaining global helium production was sourced from Qatar (15 million cubic meters), Algeria (15 million cubic meters), Russia (5 million cubic meters), Australia (4 million cubic meters), and Poland (3 million cubic meters) (Hamak 2014).

U.S. helium production is currently focused on the most economically viable gas fields near the Texas panhandle. However, in light of helium demand and the increased natural gas production from recently accessed unconventional reservoirs, one might consider also the potential for helium production from unconventional sources such as shale gas. In order to evaluate this resource, I have compiled the possible U.S. helium reserves from shale gas by using the current estimated natural gas reserves as reported by the USGS (USGS 2013) in combination with the estimated average He percentage by volume of those shale gas reservoirs provided by the Bureau of Land Management (Gage and Driskill 2004). The determination of helium potential was performed by calculating the total volume of the reservoir (in m^3) and multiplying by the average helium content of each reservoir. The total helium potential is calculated for all current shale gas reservoirs. I determined that the United States has approximately 7 billion cubic meters of helium in shale gas reservoirs (Table 2). The production of helium from unconventional resources will require increased extraction efficiency and a greater refining capacity in the future in order to take advantage of these unconventional sources.

Table 2. Reservoirs and volumes provided by the USGS's Energy Resource Program, and helium concentrations provided by the Bureau of Land Management.

		Natural Gas (Billion m^3)	Avg Helium Content %	He (Billion m^3)
Alaskan North Slope	Shublik Shale Gas (2012)	1088	0.0111	0.121
Alaskan North Slope	Brookian Shale Gas (2012)	62	0.0111	0.007
Paradox Basin	Cane Creek Shale Gas	128	0.4150	0.532
Paradox Basin	Gothic, Chimney Rock, Hovenweep Shale Gas	184	0.4150	0.763
Denver Basin	Niobrara Chalk	28	0.0642	0.018
Permian Basin	Delaware-Pecos Basins Woodford	428	0.0282	0.121
Permian Basin	Delaware-Pecos Basins Barnett	487	0.0282	0.137
Permian Basin	Midland Basin Woodword-Barnett	80	0.0282	0.023
Bend Arch-Ft. Worth Basin	Greater Newark East Frac-Barrier Gas	415	0.2550	1.059
Bend Arch-Ft. Worth Basin	Extended Continuous Barnett Shale Gas	328	0.2550	0.836
Gulf Coast	Haynesville Sabine Platform Shale Gas	1720	0.0014	0.024
Gulf Coast	Mid-Bossier Sabine Platform Shale Gas	145	0.0014	0.002
Gulf Coast	Maverick Basin Pearsall Shale Gas	250	0.0014	0.003
Gulf Coast	Eagle Ford Shale Gas	1422	0.0014	0.020
Anadarko Basin	Woodford Shale Gas	452	0.2081	0.941
Anadarko Basin	Thirteen Finger LS-Atoka Shale Gas	194	0.2081	0.404
Arkoma Basin	Woodford Shale Gas	302	0.0110	0.033
Arkoma Basin	Chattanooga Shale Gas	46	0.0110	0.005
Arkoma Basin	Fayetteville-High Gamma Ray Depocenter	257	0.0110	0.028
Arkoma Basin	Fayetteville Western Arkansas Basin	118	0.0110	0.013
Arkoma Basin	Caney Shale Gas	32	0.0110	0.004
Michigan Basin	Devonian Antrim Continuous Gas	212	0.0371	0.079
Illinois Basin	Devonian-Mississippian New Albany Shale	107	0.0371	0.040
Appalachian Basin	Northwestern Ohio Shale	75	0.0497	0.037
Appalachian Basin	Devonian Siltstone and Shale	37	0.0497	0.018
Appalachian Basin	Foldbelt Marcellus (2011)	22	0.0497	0.011
Appalachian Basin	Interior Marcelllus (2011)	2305	0.0497	1.145
Appalachian Basin	Western Margin Marcellus (2011)	58	0.0497	0.029
Appalachian Basin	Utica Shale Gas (2012)	1056	0.0497	0.525
		12037		6.977

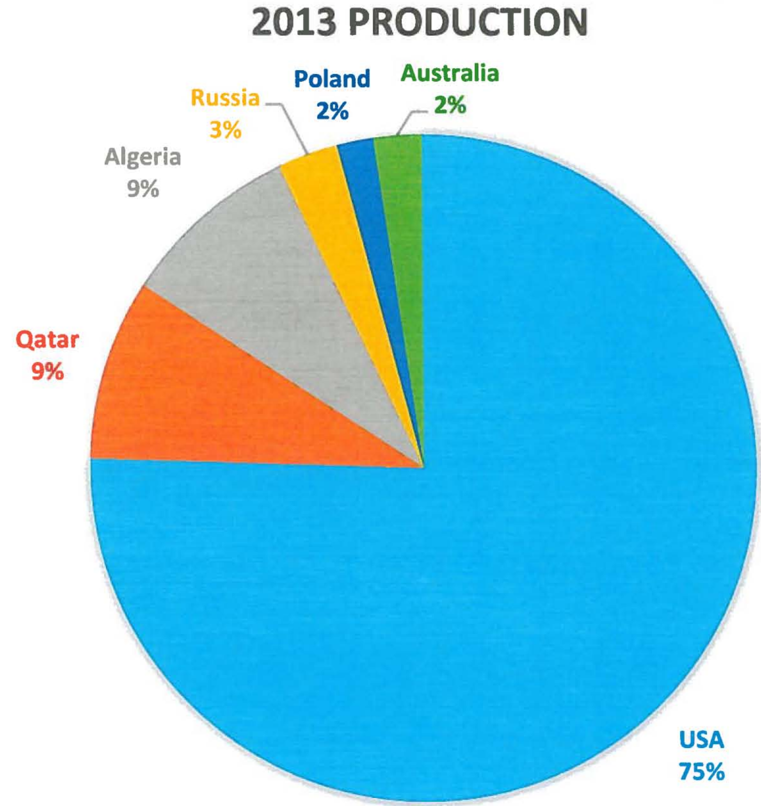

Figure 6. Global helium production by country. Source: U.S. Geological Survey, Mineral Commodity Summaries, February 2014 at http://minerals.usgs.gov/minerals/pubs/commodity/helium/mcs-2014-heliu.pdf. This figure shows the percentage of the total world production of helium by country in 2013. The United States is currently the largest producer of helium on the planet.

The National Academies 2010 helium report made global capacity and demand predictions (Figure 7) up to the year 2020 (National Research Council 2010). The figure illustrates the trend of increasing demand beginning to outstrip production by 2019 (National Research Council 2010). This prediction also assumes an increase in foreign production that has not yet been realized according to the 2014 Mineral Commodity Summary by the USGS (Hamak 2014). This prediction also shows a decrease in domestic capacity as U.S. production decreases due to the government mandated drawdown of the Cliffside Storage Facility reducing domestic supply from storage (National Research Council 2010).

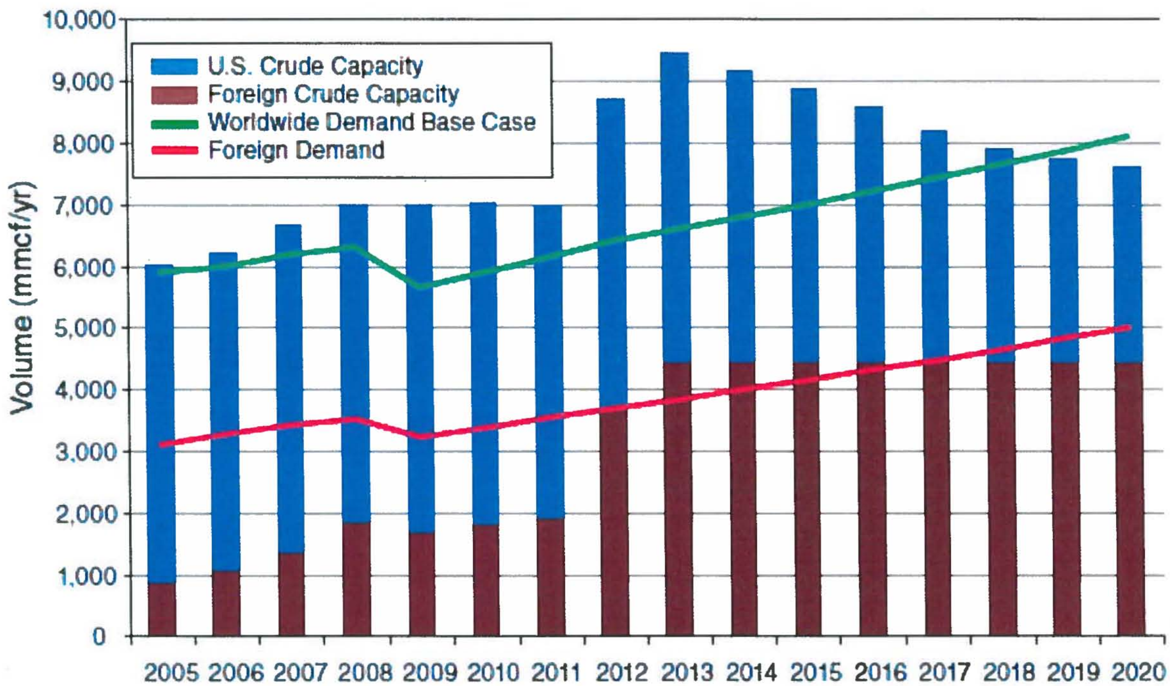

Figure 7. Helium Capacity and Demand Predictions. Source: Selling the Nation's Helium Reserve, The National Academies 2010. This figure shows that foreign crude capacity will increase with foreign demand for helium as Qatar, Algeria and other nations increase their helium production and refining capabilities. In this prediction U.S. capacity drops with the drawdown of the Federal Helium Reserve (National Research Council 2010).

Conclusions

The United States took the early lead globally in helium production in 1925 with the creation of the Federal Helium program. Subsequent investments have created an infrastructure of wells, pipelines, and long-term storage that has allowed the United States to be the largest global producer of helium. According to the USGS, the United States has the largest reserves of helium of any country in the world, composing approximately 40% of the total supply. In recent years, the United States has become a net exporter of helium as global demand has risen at a rate far greater than domestic. With this increase in global demand for helium, the United States is in the enviable position of having the largest helium reserve and greatest ability to refine and distribute to academia and industry. Even with such advantages, the United States needs to do more to expand the current infrastructure and refining capabilities to meet the expected global demand of the future.

Suggestions for Future Research

Future research should focus on the economic viability of helium production from unconventional natural gas wells. It should include the most recent developments in helium refining and the costs associated with them. Research should also look at the costs and benefits of building storage and distribution systems connected to existing unconventional natural gas sites.

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